APPLICATION OF DIFFRACTO SIGHT TO THE NONDESTRUCTIVE INSPECTION OF AIRCRAFT STRUCTURES

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INTRODUCTION

The D Sight optical set up was first assembled nearly ten years ago at Diffracto Ltd. It has received several patents, the first of which was in the United States [1]. Since the mid 1980's, D Sight has been successfully applied to surface quality inspections, particularly in the automotive and plastics industries. Recently, Komorowski et al. [2-5] have shown several potential applications of D Sight in the field of nondestructive inspection of aircraft structures. The technique has been shown to be particularly effective in locating nonvisible impact damage on large surfaces of aircraft structures built from composite materials. The early work at the IAR, NRCC led to a development program for a D Sight based device for impact damage location. In parallel, new potential applications for D Sight have been identified.

OPTICAL SETUP

The optical set-up for D Sight, described in References [6] and [7], consists of a light source, a retro-reflective screen and the object being inspected (Fig. 1). The surface being inspected must be reflective. However, rough surfaces can be made reflective by wetting with a fluid.

The D Sight effect can be explained using geometric optical principles. The light from the source is first reflected by the inspected surface. It then strikes the retro-reflective screen which attempts to return all the rays to the initial reflection point on the inspected surface. The screen, however, which consists of numerous silvered glass beads (25-75 microns in diameter), returns a cone of light to the surface, not a single ray. This imperfection of the retro-reflective screen creates the D Sight effect. As shown in Fig. 1, the imaging lens or the observer's eye is offset from the light source. When a perfectly flat surface is observed in the D Sight set-up, uniform light intensity is observed over the surface. This intensity depends on the offset of the imaging lens, the smaller the offset the higher the intensity. The change of intensity is fairly rapid with the change in the

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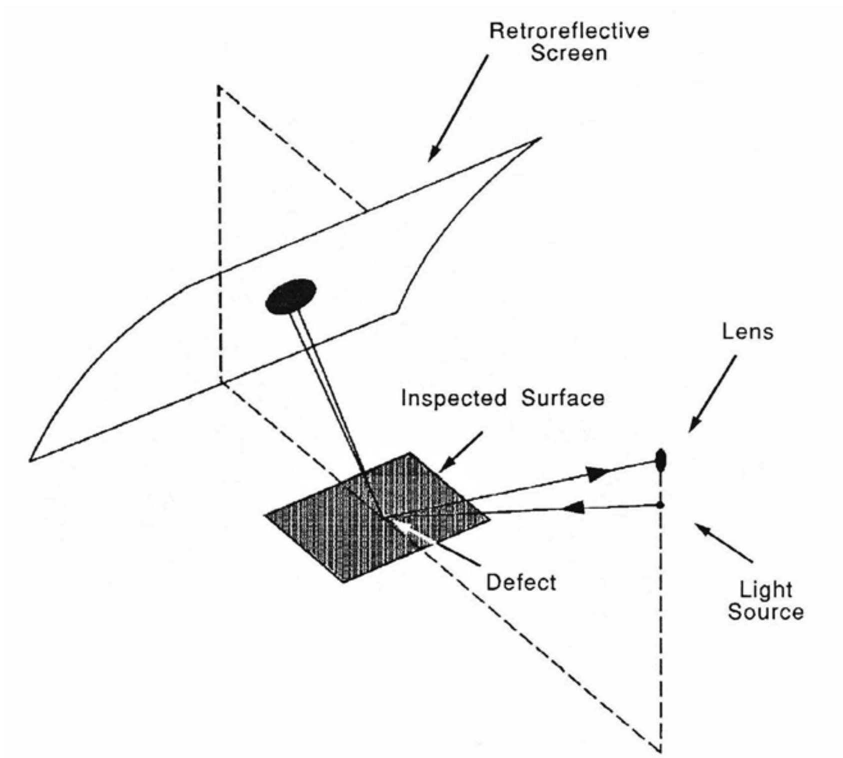

Figure 1. D Sight optical set-up.

offset angle. When a wavy surface is observed at a fixed offset angle, then the slope of a surface wave will either appear brighter or darker. The D Sight process can be viewed as a slope detecting technique with positive surface slopes looking dark and negative slopes looking bright relative to the background. The images can be photographed for documentation purposes. For more objective and automated inspections the images can be digitized and analyzed with image processing. Both flat and moderately curved (in any orientation) surfaces can be inspected using this method.

A rigorous mathematical model of D Sight has not yet been developed. In reference [8], a fairly successful computer model based on ray tracing was presented. Diffracto Ltd. has developed several algorithms which quantify surface waviness and surface imperfections from D Sight images digitized with an image processor.

To date D Sight has been shown to have potential as a tool for scanning large surface areas of aircraft for impact damage and delaminations in composites and for corrosion and cracks in metallic structures [2-5]. In the aircraft fabrication field D Sight was shown to be effective in locating cold worked holes [4].

BONDING IN METALLIC STRUCTURES

Testing of a de Havilland Dash 8 fuselage at the Aeroacoustics facility of the IAR provided an opportunity to experiment with an IAR built D Sight prototype. D Sight images in which bonded stiffeners of the Dash 8 fuselage could be clearly distinguished through the fuselage skin (Fig. 2) were obtained. At the time it was speculated that an improperly bonded (disbonded) stiffener would not 'read-through' the skin. The observation warranted further investigation.

Recent D Sight publications have attracted interest from the SAAB-SCANIA Aircraft Division which provided a specimen for evaluation. This was an aluminum alloy aircraft skin with bonded doubler (both approximately 1.5 mm thick). A 'J' stiffener was bonded to the doubler and the specimen was ~250 mm long. In Fig. 3, ambient (top) and D Sight (bottom) images are compared. The 'J' stiffener running across the specimen middle is easily distinguished in the D Sight view. On the same image in the center below the stiffener an elliptical perturbation can be distinguished. An ultrasonic C-scan (Fig. 4) of the specimen indicated (dark zones on the C-scan) that this perturbation was due to a disbond and porosity in the adhesive between the skin and the doubler. It should be stressed that the D Sight inspection was completed in less that 10 minutes (specimen highlighting, image acquisition and printing) from receipt of the specimen from SAAB.

The D Sight signature in the case of a disbond is not as strong as in the case of impact damage. Image processing techniques should be considered in the future to facilitate disbond location with D Sight.

D SIGHT AIRCRAFT INSPECTION SYSTEM (DAIS)

Early aircraft D Sight inspections were carried out with an IAR designed prototype. This was the first 'closed' system in which the optical components were fixed in a frame and shrouded providing freedom from ambient light interference. The experience gained using this system influenced the design of the D Sight Aircraft Inspection System (DAIS).

The DAIS consists of an inspection head which includes the D Sight optical components and a CCD camera, a transportable computer with frame grabber and a highlighter applicator. The head shrouds the optical system and allows operation in any ambient light environment. In contrast to the open D Sight systems all components in the head are fixed which insures inspection repeatability. To avoid making the inspection head too large and bulky the optimized optical path was folded as shown in Figure 5.

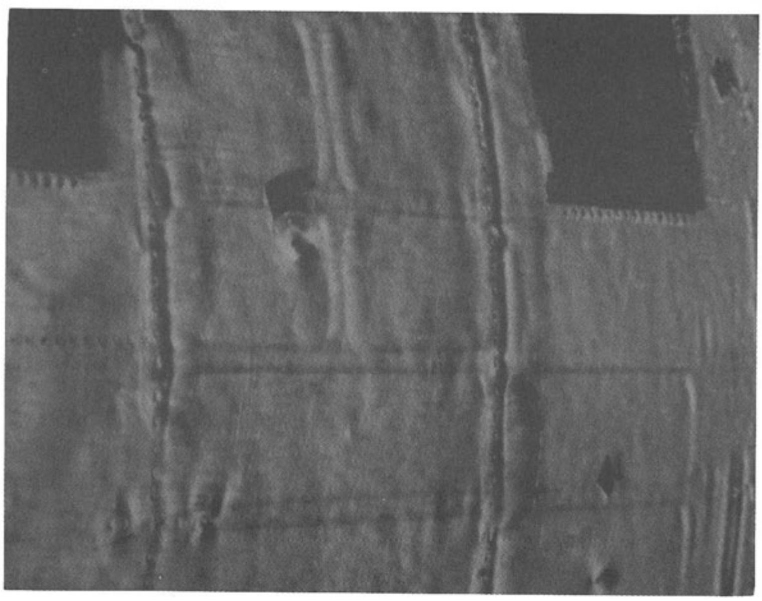

Figure 2. D Sight image - Dash 8 fuselage with bonded stiffeners.

The size of the DAIS head is primarily driven by the required field of view (FOV). The FOV governs the spatial sensitivity of D Sight to the defect area (i.e. impact damage) since the signature size and contrast in the image is proportional to the defect size and depth. Human factors also influenced the FOV choice, since the size and weight of the inspection head determined how easily the unit could be carried and maneuvered into position.

The selected FOV not only affects the sensitivity of the DAIS but also the speed with which an area can be inspected. A smaller head dictates that more D Sight inspection head placements are required to fully inspect a given structure. Each head placement results in one D Sight image. Inspections carried out on current fighter aircraft have shown that a DAIS using a FOV of 0.3 m^2 requires about 600 images. In practice not all surfaces have to be inspected for impact damage and a figure of 300 images is more realistic. As the format used at present needs 256 kB per image the whole aircraft inspection record of 80 MB can be stored using two 3.5" magneto-optic floppy diskettes.

A typical D Sight inspection consists of equipment set up, surface preparation (cleaning and highlighting), head placement, image analysis and storage/printing and inspection result reporting. Image analysis, printing and reporting can be postponed if the images are stored. At Diffracto dedicated software has been written to control various DAIS operations which help organize the inspection, image storage and archiving. D Sight images can be viewed on the computer monitor in real time or displayed from storage. Three development model inspection heads and a portable computer are shown in Fig 6.

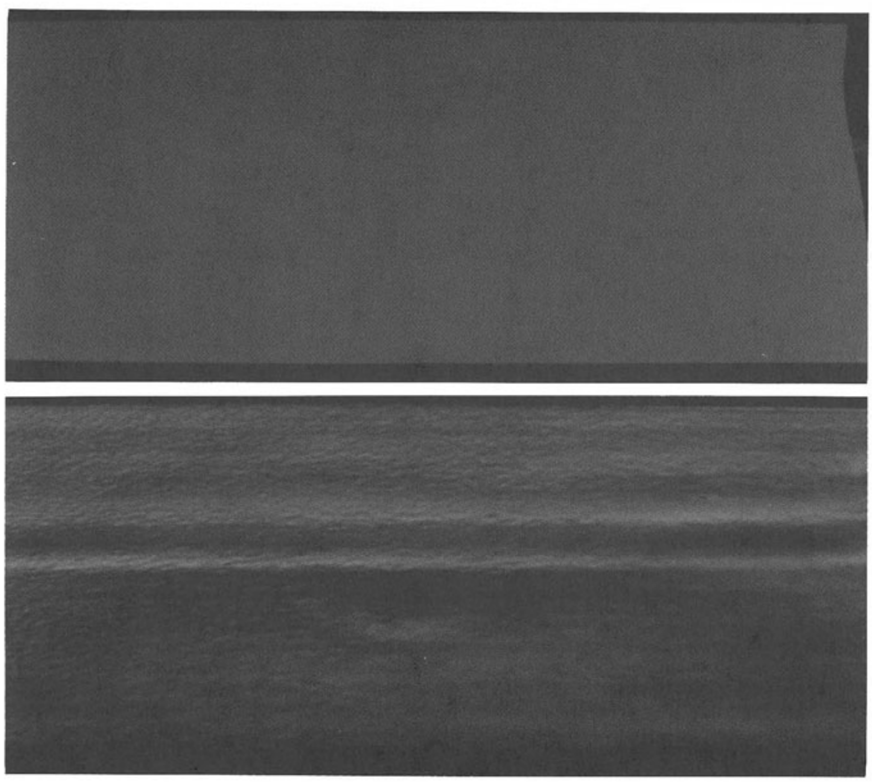

Figure 3. Ambient (top) and D Sight view of the SAAB specimen.

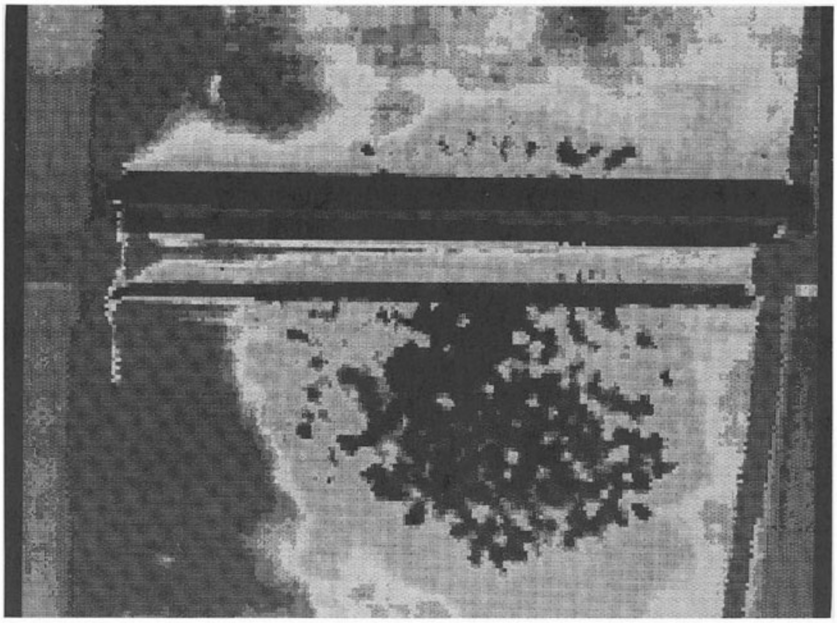

Figure 4. Ultrasonic C-scan of the SAAB specimen.

FIELD EXPERIENCE

Limited experience using DAIS in the field has led to some minor equipment modifications and to refinement of the highlighting procedure. Two technicians using a DAIS are capable of inspecting more than 18 m^2/h of aircraft surface.

The equipment was recently used on a trial basis to inspect an aging transport aircraft for corrosion (Fig. 7). While full results of this trial are not yet available it demonstrated that D Sight inspections can be conducted out of doors in bright sunlight. The analysis of D Sight images showed various features which were attributed to corrosion and possible areas of corrosion were mapped on the aircraft. This experience has confirmed that D Sight has a potential for locating corrosion in fuselage lap joints. A carefully structured and executed program in the area of D Sight application to corrosion

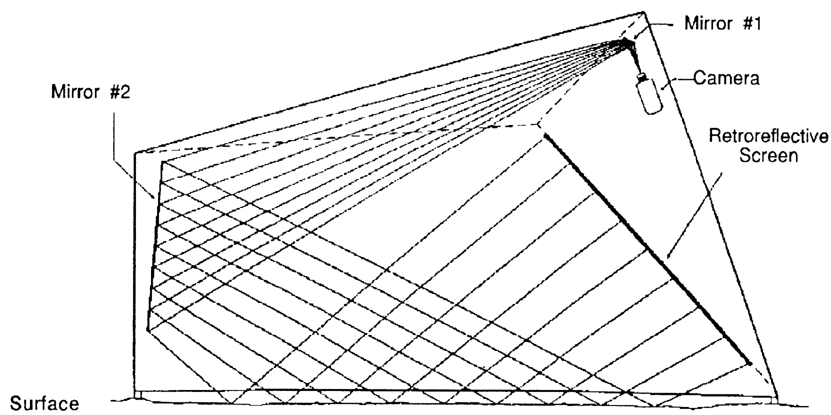

Figure 5. Folded optical train.

detection is needed before this technique can be used on regular basis. The DAIS development model would have to be modified for optimum corrosion detection sensitivity. Key D Sight image features characteristic to corrosion should be identified. To reduce inspector training requirements, appropriate image processing techniques should be developed.

CONCLUSIONS

A D Sight Aircraft Inspection System (DAIS) has been built and successfully used in the field. Up to 18 m^2/h of an aircraft surface can inspected for impact damage.

Mathematical modeling of D Sight should be pursued to assist in image interpretation and equipment design.

Non destructive inspection of bonded joints has been added to a growing list of potential applications of D Sight. The other areas are impact damage and delaminations in composites and corrosion, cracks and cold working of holes in metals.

For each potential application of D Sight a carefully structured and executed development program is needed. Characteristic image features have to be identified and correlated with actual damage levels. Reliability and sensitivity have to quantified individually for every application.

ACKNOWLEDGMENTS

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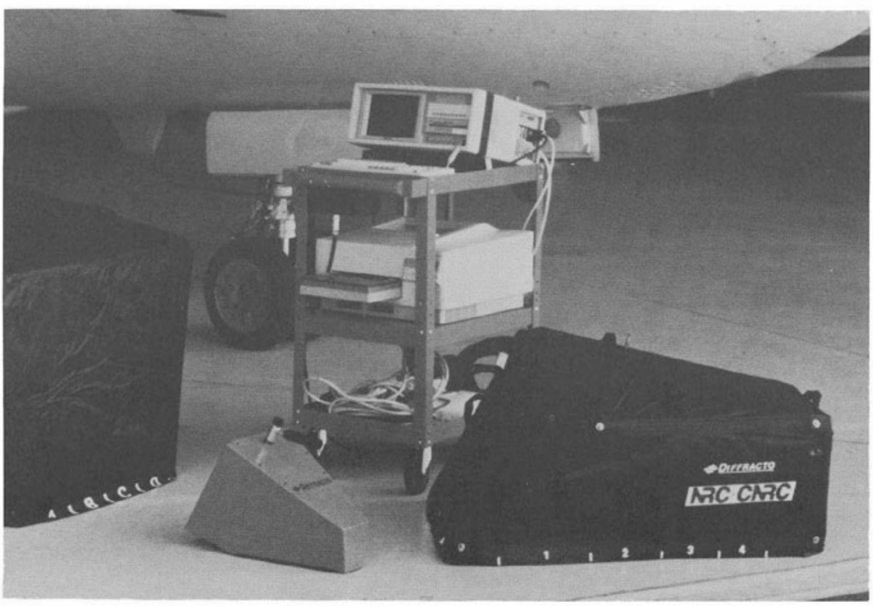

Figure 6. DAIS advanced development models in a hangar.

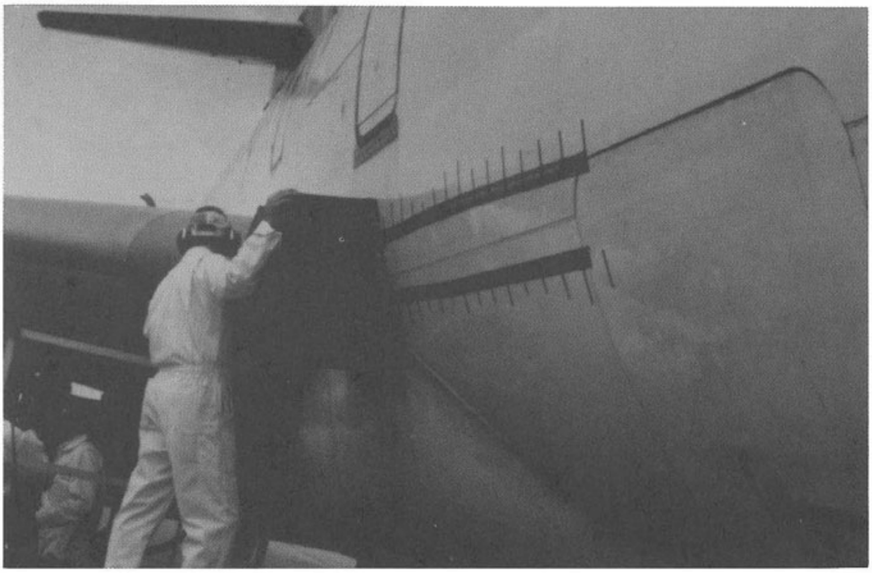

Figure 7. DAIS inspection of a horizontal lap joint.

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